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Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: DETERMINING THE DIELECTRIC PROPERTIES OF WOOD
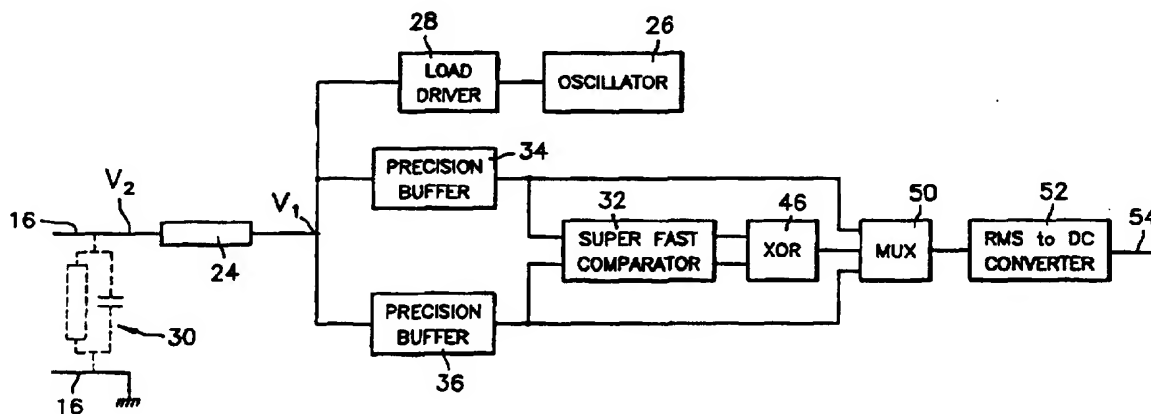
(57) Abstract

The dielectric properties of wood (12) in a wood-drying kiln (10) is determined by having the wood disposed between electrodes (16), applying a sinusoidal voltage (38) to the electrodes via a resistive element (24), determining the phase angle (ω) between the applied voltage (V_1) and the voltage (V_2) across the electrodes and the magnitude of these voltages, and determining from these values the phase angle and magnitude of the complex impedance between the electrodes.

-- DETERMINING THE DIELECTRIC PROPERTIES OF WOOD --

This invention relates to a method of
determining the dielectric properties of wood, in
5   particular for purposes of deriving therefrom a measure
of the moisture content of the wood, and to means for
use in such method.

The moisture content of wood can be expressed
as the difference between the wet weight and the dry
10   weight of the wood, divided by the dry weight.

When drying wood in a wood drying kiln, an
end-point moisture content of 5% to 20% is normally
required. Traditional methods of measuring the
moisture content of wood, whilst reasonably accurate
15   towards the end-point moisture content, become less
accurate at higher values of the moisture content. At
a moisture contents of above 30%, the traditional
methods become completely unreliable.

For the proper control of the environment in
20   which wood is dried, for example, in a wood-drying
kiln, it is important for the moisture content of the
wood to be known accurately while the moisture content
is still relatively high, e.g. above 30%. If the
moisture content is accurately known at these
25   relatively high values it becomes possible to
accelerate the drying process considerably, without
causing undue stresses in the wood.

According to the present invention there is
provided a method of determining the dielectric
30   properties of wood, which method includes having the
wood disposed between electrodes, applying a varying

electrical signal to the electrodes, measuring the
electrical values of the signal, and determining from
the measured values the phase angle and magnitude of
the complex impedance between the electrodes.

5   The varying electrical signal can
conveniently be a sinusoidal voltage and can be applied
to the electrodes via a resistive element, and the
phase angle between the applied voltage (i.e. the
voltage before the resistive element) and the voltage
10 across the electrodes (i.e. the voltage after the
resistive element), and the magnitudes of said voltages
determined. From this it is possible to derive the
phase angle and magnitude of the complex impedance
between the electrodes.

15   It will be understood that one of the
electrodes may be ground, i.e. the structure on which
the wood is supported, where the structure is of an
electrically conductive material.

         The measured values may be determined in an
20 electronics module which is in close proximity to the
electrodes, and the phase angle and magnitude of said
complex impedance may be determined from the measured
values in data processing means which is remote from
the electrodes, there being a data link between the
25 electronics module and the data processing means.

         Further according to the invention there is
provided means for determining the dielectric
properties of wood, which comprises a pair of
electrodes between which the wood can be disposed, and
30 means for determining the phase angle and magnitude of
the complex impedance between the electrodes.

         Still further according to the invention

there is provided a wood-drying installation which
comprises a wood-drying kiln and means for determining
the moisture content of wood being dried in the kiln,
said means comprising a pair of electrodes between
5   which the wood in the kiln can be disposed, and means
for determining the phase angle and magnitude of the
complex impedance between the electrodes.

The means for determining the phase angle and
magnitude of the complex impedance between the
10 electrodes may comprise a resistive element connected
in series with one of the electrodes, means for
applying a sinusoidal voltage to the electrodes via the
resistive element, and means for determining the phase
angle between the applied voltage and the voltage
15 across the electrodes and the magnitudes of said
voltages.

The invention will now be described in more
detail, by way of example, with reference to the
accompanying diagrammatic drawings.

20   In the drawings:
Figure 1 is an end view of a stack of timber, in a
wood drying kiln provided with measuring means in
accordance with the invention;
Figure 2 is a block diagram of the measuring
25 means;
Figure 3 shows certain voltage waveforms; and
Figure 4 is a phasor diagram of the voltages.

Referring now the drawings in more detail,
reference numeral 10 indicates a wood-drying kiln in
30 which there is a stack of timber 12. The timber 12 is
arranged in layers which are spaced from one another by
means of spacers. The environment inside the kiln is
controlled according to the moisture content of the

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timber.

To determine the moisture content of the
timber accurately, the kiln is provided with measuring
means comprising an electronics module 14 outside but
5   in close proximity to the kiln, a pair of electrodes 16
inside the kiln and coupled to the module 14 by means
of electrical connections 18, and a remote data
processor 20 which is connected to the electronics
module 14 by means of a data link 22. Where there are
10   a number of kilns 10, each with its own electronics
module 14, the various electronics modules may all be
connected to the same data processor 20.

The electrodes 16 are in the form of metal
plates and are simply inserted into the spaces between
15   layers in the stack 12. It is an important feature of
the invention that the electrodes 16 need not be
cleaned prior to insertion into the stack, as operation
of the apparatus is not affected by the degree of
physical contact with the timber. The size and exact
20   position of the electrodes is also not important. If
the size and/or position of the electrodes is changed,
all that will be required is for the system to be
recalibrated.

The electronics module 14 serves to measure
25   the values that are required to determine the phase
angle and magnitude of the complex impedance between
the electrodes 16. This is achieved in the following
manner. The electronics module 14 includes a resistive
element 24, connected in series with one of the
30   electrodes, and an oscillator 26 and associated driver
28 whereby a sinusoidal voltage can be applied to the
electrodes via the resistive element. The oscillator
26 has a frequency which is in the ultra-sonic range,
for example in the order of 40kHz. The impedance

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indicated at 30 represents the impedance between the
electrodes 16.

The electronics module 14 further comprises a
super-fast comparator 32 which is connected via a
5   precision buffer 34 to the output of the driver 28, and
via a precision buffer 36 to one of the electrodes, the
other electrode being connected to ground.

The waveform of the applied voltage (i.e. the
output of the driver 28) is indicated at 38 in Figure
10 3, whereas the waveform of the voltage across the
electrodes 16 (i.e. after the resistive element 24) is
indicated by reference numeral 40 in Figure 3. In
Figure 4 the applied voltage 38 is indicated by the
phasor V_1 and the voltage across the electrodes by the
15 phasor V_2. Because the impedance 30 is a complex
impedance, there is a phase difference between the
voltages V_1 and V_2, this being indicted by the angle ω
in Figure 4. V_x in Figure 4 is the voltage across the
resistive element 24.

20   The comparator 32 serves to convert the
sinusoidal voltages 38 and 40 to square-wave voltages
42 and 44 respectively.

The electronics module 14 further comprises
an exclusive OR (XOR) circuit 46 whose output is
25 indicated at 48 in Figure 3. The RMS value of the
output 48 varies in proportion to the phase difference
between the voltages 38 and 40. The outputs of the
buffers 34 and 36 and the output of the XOR circuit 46
are fed via a multiplexer 50 to an RMS-to-DC converter
30 52. The multiplexer 50 has a relatively slow sampling
rate as compared with the frequency of the applied
signal.

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Output 54 of the RMS-to-DC converter 52 is
relayed to the data processor 20 via the data link 22.

The phase angle of the impedance 30 is
determined by making use of the following equations:

$$a = V_2 * \cos \omega$$
$$b = V_2 * \sin \omega$$
$$d = V_1 / \{-a * (a/b - b)\}$$
$$c = a * d/b$$
$$C_x = d/\{R * 2\pi f\}$$
$$R_x = R/(c-1)$$

Where: V_1 is the amplitude of the applied
                    voltage;

            V_2 is the amplitude of the voltage
                    across the electrodes;

            ω is the phase difference between the
                    voltages V_1 and V_2;

            R   is the series resistive element 24;

            f   is the frequency of the applied
                    voltage;

            C_x is the value of the capacitive
                    component of the complex impedance
                    30; and

            R_x is the resistive component of the
                    complex impedance 30.

assuming that the capacitive and a resistive components
of the impedance are in parallel.

In the event that the complex impedance
includes an inductive component (L_x) in parallel with
the capacitive component C_x, the value of L_x can be
determined independently from C_x by measuring the
complex impedance at two different frequencies.

It will be appreciated that other methods can

be used to determine the phase angle and magnitude of the complex impedance 30.

The moisture content of the timber is derived by suitable data processing in the data processor 20.

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CLAIMS:

1.   A method of determining the dielectric
properties of wood, **characterised in that** it includes
the steps of having the wood (12) disposed between
electrodes (16), applying a varying electrical signal
to the electrodes, measuring the electrical values of
the signal, and determining from the measured values
the phase angle and magnitude of the complex impedance
between the electrodes.

2.   A method as claimed in claim 1, **characterised
in that** the varying electrical signal is a sinusoidal
voltage (38) applied to the electrodes (16) via a
resistive element (24); and that the measured values
are the phase angle (ω) between the applied voltage
(V_1) and the voltage across the electrodes (V_2), and
the magnitudes of said voltages.

3.   A method as claimed in claim 2, **characterised
in that** the measured values are determined in an
electronics module (14) which is in close proximity to
the electrodes; and that the phase angle and magnitude
of said complex impedance is determined from the
measured values in data processing means (20) which is
remote from the electrodes; there being a data link
(22) between the electronics module and the data
processing means.

4.   Measuring means for determining the
dielectric properties of wood, **characterised in that** it
comprises a pair of electrodes (16) between which the
wood (12) can be disposed, and means (14, 20) for
determining the phase angle and magnitude of the
complex impedance between the electrodes.

5.   A wood-drying installation which comprises a

wood-drying kiln (10) and means for determining the
dielectric properties of wood (12) being dried in the
kiln, **characterised in that** said means comprises a pair
of electrodes (16) between which the wood in the kiln
can be disposed, and means (14, 20) for determining the
phase angle and magnitude of the complex impedance
between the electrodes.

6.   A wood-drying installation as claimed in
claim 5, **characterised in that** the means for
determining the phase angle and magnitude of the
complex impedance between the electrodes comprises a
resistive element (24) connected in series with one of
the electrodes (16), means (26, 28) for applying a
sinusoidal voltage (38) to the electrodes via the
resistive element, and means (34..46) for determining
the phase angle (ω) between the applied voltage (V_1)
and the voltage (V_2) across the electrodes and the
magnitudes of said voltages.

7.   A wood-drying installation as claimed in
claim 6, **characterised in that** the resistive element
(24) and means (34...46) for determining the phase
angle (ω) between the applied voltage (V_1) and the
voltage (V_2) across the electrodes and the magnitudes
of said voltages form part of an electronics module
(14) which is in close to the electrodes; and in that
it further comprises data processing means (20) which
is remote from the electrodes, for determining from the
measured values the phase angle and magnitude of said
complex impedance; there being a data link (22) between
the electronics module and the data processing means.

8.   A method of determining the dielectric
properties of wood, substantially as herein described
and illustrated.

9.   Measuring means for determining the dielectric properties of wood, substantially as herein described and illustrated.

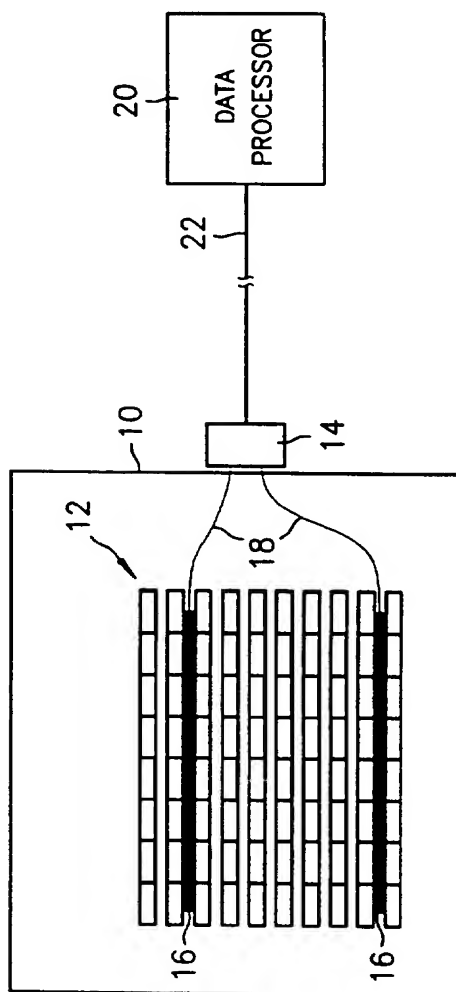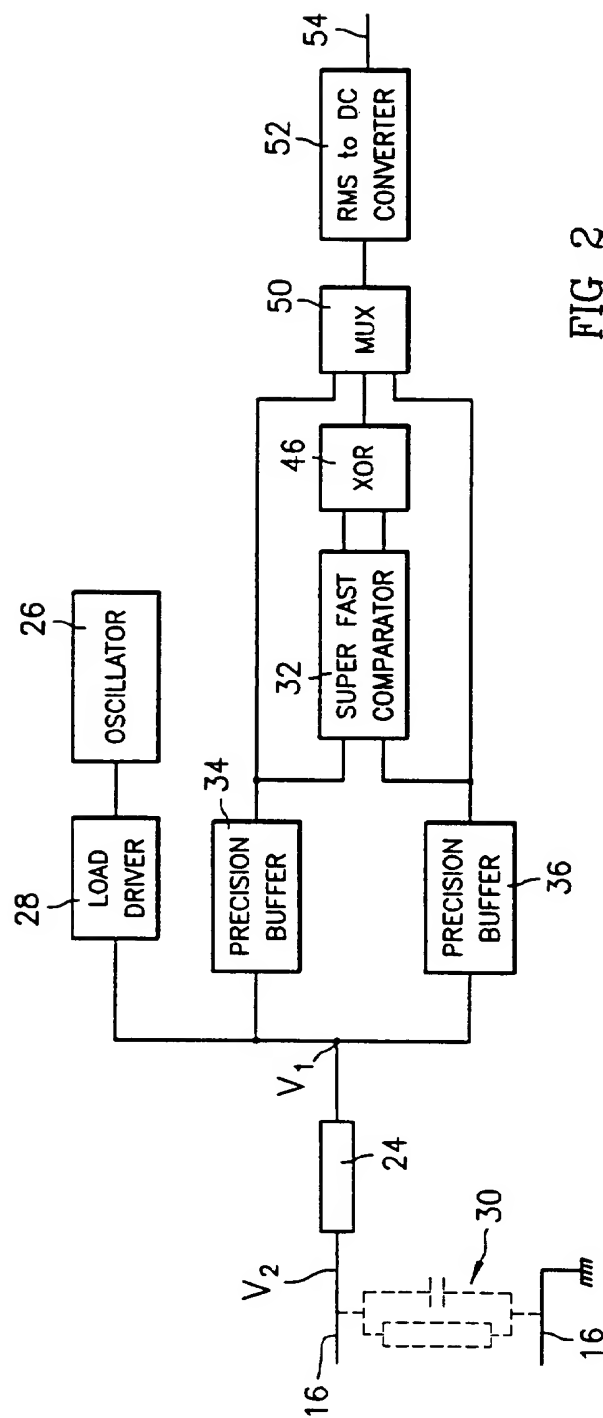10.   A wood-drying installation, substantially as herein described and illustrated.
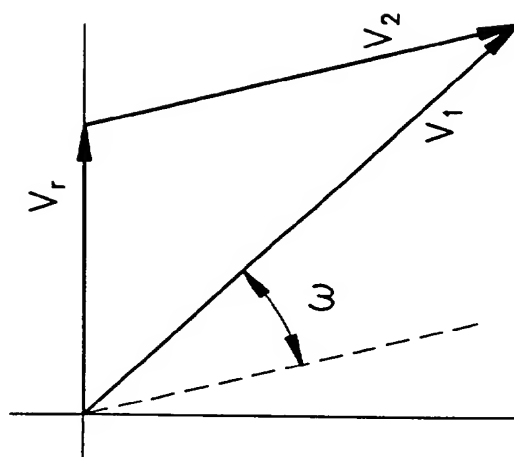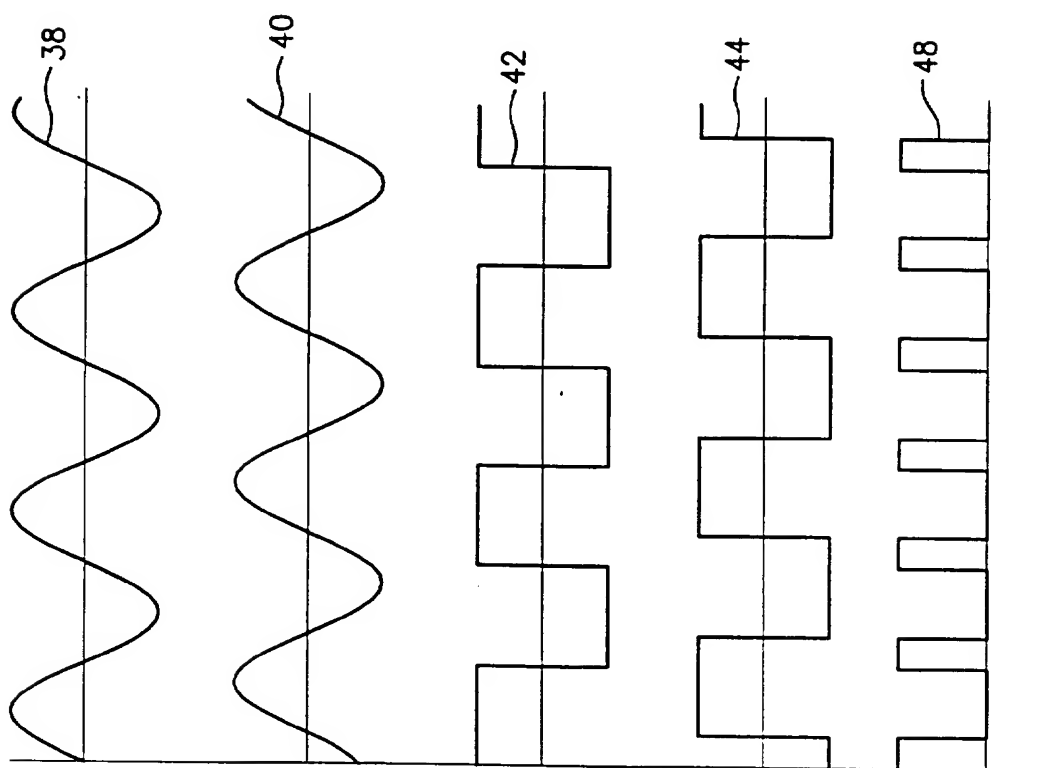
FIG · 1

FIG 2

FIG 4

FIG 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/03604

A.	CLASSIFICATION OF SUBJECT MATTER

IPC(6)   :G01R 27/02
US CL   :324/664,683

According to International Patent Classification (IPC) or to both national classification and IPC

B.	FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 324/664, 683

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
Search Terms: Wood^ (Dried or Dry)^ 324/Clas ^ phase

C.	DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 3,992,665 (PREIKSCHAT), 16 November 1976, see entire text.	1-7
A	US, A, 4,181,881 (PREIKSCHAT), 01 January 1980, see entire text.	1-7

☐ Further documents are listed in the continuation of Box C.   ☐   See patent family annex.
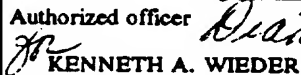
*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O"	document referring to an oral disclosure, use, exhibition or other means	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search

22 APRIL 1996

Date of mailing of the international search report

27 AUG 1996

Name and mailing address of the ISA/US
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Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/03604

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 8-10
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

   Claims 8-10 do not have means or steps properly defined. These claims are omnibus in nature as the phrase "substantially herein described" provides no meaningful limitations in order to determine an appropriate field of search.

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1))(July 1992)*